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A Comparison of Iron and Steel Production Energy Intensity in China and the U.S.

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Abstract

The goal of this study was to develop a methodology for making an accurate comparison of the energy intensity of steel production in China and the U.S. The methodology addresses issues related to boundary definitions, conversion factors, and industry structure. In addition to the base case analysis, six scenarios were developed to assess the effect of different factors such as the share of electric arc furnace (EAF) steel production, conversion factors for the embodied energy of imported and exported intermediary and auxiliary products, and the differences in net calorific values of the fuels. The results of the analysis show that for the whole iron and steel production process, the final energy intensity in 2006 was equal to 14.90 GJ/tonne crude steel in the U.S. and 23.11 GJ/tonne crude steel in China in the base scenario. In another scenario that assumed the Chinese share of electric arc furnace production in 2006 (i.e. 10.5%) in the U.S., the energy intensity of steel production in the U.S. increased by 54% to 22.96 GJ/tonne crude steel. Thus, when comparing the energy intensity of the U.S and Chinese steel industry, the structure of the industry should be taken into account.

1. Introduction

Production of iron and steel is an energy-intensive manufacturing process. In 2006, the iron and steel industry accounted for 13.6% and 1.4% of primary energy consumption in China and the U.S., respectively (Zhang et al., 2010; U.S. DOE/EIA, 2010a). The energy efficiency of steel production has a direct impact on overall energy consumption and related carbon dioxide (CO2) emissions. The goal of this study is to develop a methodology for making an accurate comparison of the energy intensity (energy use per unit of steel produced) of steel production in China and the U.S. The methodology addresses issues related to boundary definitions, conversion factors, and indicators in order to develop a common framework for comparing steel industry energy use in these two countries.

2. Methodology

This study uses a bottom-up, physical-based methodology to compare the energy intensity of China and U.S. crude steel production in 2006. This year was chosen in order to maximize the availability of comparable steel-sector data. However, data published in China and the U.S. are not always consistent in terms of analytical scope, conversion factors, and information on adoption of energy-saving technologies. This study is primarily based on published annual data from the China Iron and Steel Association and National Bureau of Statistics in China and the Energy Information Agency in the U.S.

2.1. Boundaries

In this study, the iron and steel industry includes all coke making, pelletizing, sintering, iron making, steel making, steel casting, hot rolling, cold rolling, and processing such as galvanizing or coating (Figure 1). This boundary definition is used for the calculations of energy use and energy intensity for both the Chinese and U.S iron and steel industries.

Regarding accounting for energy used for coke production within the iron and steel industry, there are a few special considerations. This study includes the total coal input used as a feedstock for coke making and also as a fuel in other parts of the steel making process. Only net imported coke (either produced in other domestic industries or imported from other countries) is included as a source of input energy to the iron and steel industry. Net imported coke is total imported coke minus total exported coke. The energy value of the coke produced in the coke making process within the iron and steel industry and used in the iron making process is not included since the coal initially used to produce the coke is already accounted for within the boundary. This study does not count the coke trade that occurs within the boundary, as the total coal input to the industry is already taken into account. This study takes net imported (to the boundary of the industry defined in Figure 1) pig iron, direct-reduced iron (DRI), pellets, lime, oxygen, and ingots, blooms, billets, and slabs into account by adding the energy used for production of these products to the total energy input to the iron and steel industry.

In addition, this study does not include energy consumption associated with other energy-intensive products manufactured for the industry (e.g., electrodes, ferroalloys, refractories, etc.). These products could be included in a more extensive, life-cycle analysis study of the industry, but are excluded here because the focus of this study is on iron and steel production. This is the approach taken by Stubbles (2000). This study also does not take into account the embodied energy of the scrap used in the iron and steel industry. Finally, energy demand for mining and beneficiation of iron ores is not included in this analysis.

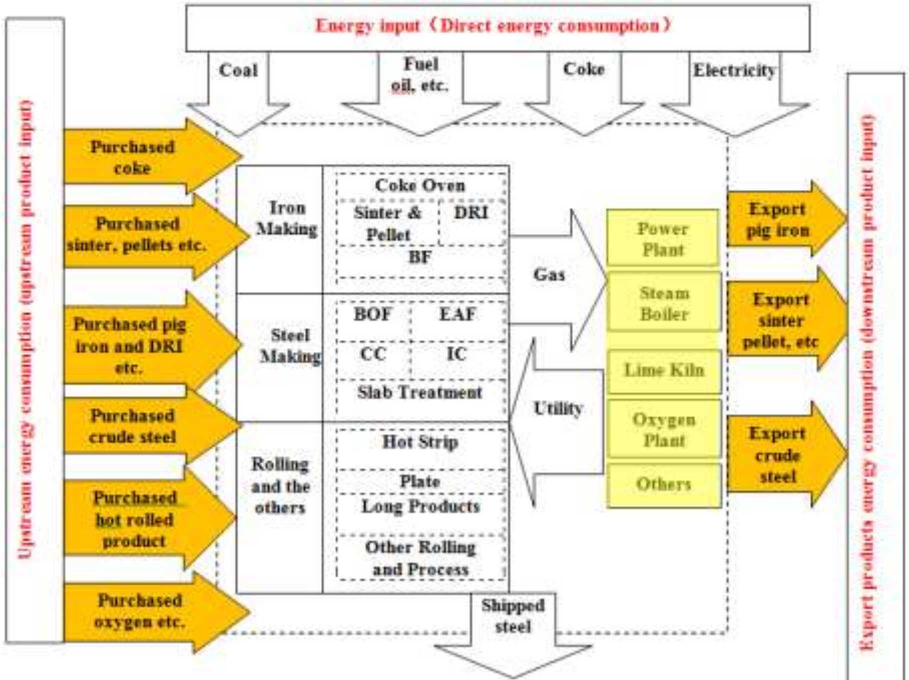

Figure 1: Flowchart of Iron and Steel Sector Boundaries Used in this Study

2.2. Conversion Factors

In order to calculate comparable energy use and energy intensity values, common conversion factors must be used to convert the physical quantities of fuels consumed to produce steel to energy values. In addition, common conversion factors must also be used to calculate electricity values. These conversion factors are explained below.

2.2.1. Fuel Conversion Factors

The heating value or calorific value of a fuel source represents the amount of heat released during combustion. This study uses the lower heating value – or net calorific value (NCV) – to convert physical quantities of fuel to a common energy unit. NCV conversion factors for China are provided in the China Energy Statistics Yearbook 2006 and 2009 (NBS 2007, 2010a) and for the U.S. are provided in the EIA's Annual Energy Review (U.S. DOE/EIA 2007, 2009). Where available, the NCV of the fuels in 2006 is used. In addition, the typical NCVs for fuels are also provided in various IEA publications. Table 1 provides the NCV conversion factors for different fuels for China and the U.S.

Table 1: Fuel Conversion Factors for China and the U.S.

Fuel	IEA-Typical		Country-Specific				Unit
	IEA-Typical	Source	China	Source	U.S.	Source	
Other Bituminous coal (used as fuel)	24.05	IEA 2005	20.91	NBS 2007	25.65	EIA 2009	MJ/kg
Coking coal	28.20	IEA 2005	26.34	NBS 2007	30.56	EIA 2009	MJ/kg
Coke oven coke	27.45	IEA 2005	28.44	NBS 2007	28.85	EIA 2009	MJ/kg
Natural gas	35.04	IEA 2008c	38.93	NBS 2007	38.33	EIA 2009	MJ/m3
Residual Fuel oil	42.18	IEA 2005	---		44.18	EIA 2007	MJ/kg
Distillate Fuel Oil	40.19	IEA 2008c	41.82	NBS 2007	40.94	EIA 2007	MJ/kg
LPG	46.15	IEA 2005	50.18	NBS 2007	45.81	EIA 2009	MJ/kg
Other washed coal	-		10.47	NBS 2007			MJ/kg
Crude oil	42.85	IEA 2008c	41.82	NBS 2007			MJ/kg
Gasoline	47.10	IEA 2005	43.07	NBS 2007			MJ/kg
Kerosene	46.22	IEA 2005	43.07	NBS 2007			MJ/kg
Diesel	45.66	IEA 2005	42.65	NBS 2007			MJ/kg
Other petroleum products	-		35.17	NBS 2007			MJ/kg
Tar	-		33.45	NBS 2009			MJ/kg
Benzene			41.82	NBS 2009			MJ/kg

2.2.2. Electricity Conversion Factors

Final (or site) electricity is the electricity consumed at the production facility. This value does not include the primary energy used to generate, transmit, and distribute electricity to the site. To convert final electricity to primary energy, the average efficiency of power generation and transmission and distribution (T&D) losses must be taken into account. The conversion factors to convert electricity from final to primary energy for the U.S. and China in 2006 are calculated based on net heat rates and T&D in both countries along with World Steel Association (WORLDSTEEL) conversion factor are presented in Table 2.

Table 2: Final to Primary Energy Conversion Factor in 2006

	China	U.S	WORLDSTEEL
Final Conversion Factor with T&D losses (kgce/kWh)	0.376	0.379	0.334
Final Conversion Factor without T&D losses (kgce/kWh)	0.350	0.354	
Sources	NBS 2009; Anhua and Xingshu, 2006	EIA 2010a; EIA 2008	WORLDSTEEL 2008b

2.2.3. Conversion Factors for Purchased Auxiliary/Intermediary Products

For this study, the international average energy conversion factors are used for products that are purchased externally and imported or exported by the iron and steel industry since imported products can be from different countries and will thus vary in their energy consumption during production due to differences in production technology and energy structure. The energy conversion factors for external products in this study are provided by the World Steel Association (WORLDSTEEL) (WORLDSTEEL, n.d.;

WORLDSTEEL, 2008b). Table 3 provides energy conversion factors for purchased fuels and materials as well as imported auxiliary/intermediary products along with the share of electricity use for production of each product.

Table 3: Conversion Factors for Purchased Fuels & Auxiliary/Intermediary Products

	Coke [a]	Pig Iron [a]	Coal based [a] DRI	Gas based [a] DRI	Pellets [a]	Crude Steel [b]	Lime [a]	Oxygen [a]
	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/m^3
WORLDSTEEL Factors (Primary Energy)	4.0	20.9	17.9	14.1	2.1	18.9	4.5	6.9
China-specific value						18.54		
WORLDSTEEL Factors (Final Energy) [c]	3.7	19.8	17.0	13.4	2.1	16.5	4.1	2.5
China-specific value						17.4		
Electricity share in total Primary Energy	11%	8%	8%	8%	0	20%	15%	100%
China-specific value					0	10%		

[a] WORLDSTEEL, n.d. [b] WORLDSTEEL, 2008a

[c] The 9.8 MJ/kWh conversion factor from WORLDSTEEL was used to convert the WORLDSTEEL conversion factors for Purchased Fuels & Auxiliary/Intermediary Products from primary to final energy using the percentages of electricity use for the production of each product given in the table above.

3. Base Year Production, Trade and Energy Use Data

3.1. Production and Trade Data

3.1.1. Production Data for the U.S.

Table 4 shows the production data for pig iron, DRI, crude steel, ingots, blooms, billets, slabs, and steel products (finished steel). For the calculation of the energy intensities, crude steel production is used as the denominator. However, it should be noted that the casting, rolling and finishing processes are also within the boundary of the analysis.

Table 4: Production and Trade Data for Pig Iron, DRI, Crude Steel, Ingot, Blooms, Billets, and Slabs, and Steel Products in U.S in 2006 (Mt) (USGS, 2008)

Product	Production	Exports	Imports	Net Imports	Used in industry
Pig Iron	37.9	0.813	6.73	5.92	43.8
DRI	0.24	-	2.61	2.61	2.85
Crude Steel	98.2	-	-	-	-
Ingots, Blooms, Billets, Slabs	-	0.20	8.46	8.26	-
Steel Products	99.3	8.83	41.1	32.3	-

3.1.2. Production and Trade Data for China

Table 5 lists China's production, exports and imports of pig iron, DRI, crude steel, and steel products in 2006. Net exports are 0.7 Mt of pig iron and 8.67 Mt of steel billets. Net imports are 0.3 Mt of DRI, and 0.1 Mt of steel ingots.

Table 5: Production, Imports and Exports of Pig Iron, DRI, Crude Steel, Ingots, Billets, and Steel Products in China, 2006 (Mt)

Product	Production	Imports	Exports	Net Imports	Used in industry
Pig Iron	413.64	0.17	0.87	-0.70	412.94
DRI	0.21	0.31	0.01	0.30	0.51
Crude Steel	421.02	-	-	-	-
Steel Ingots	-	0.14	0.04	0.10	-
Steel Billets	-	0.37	9.04	-8.67	-
Steel Products	399.97*	18.51	43.01	-24.50	375.47

Source: Editorial Board of the China Iron and Steel Industry Association Yearbook, 2006.

* In order to avoid double-counting of steel products, this number was calculated as 95% of crude steel.

3.2. Energy Use Data

3.2.1. Energy Use of the U.S. Iron and Steel Industry Based on EIA Reported Data

In addition to the first use of energy, which is the energy used as fuel and nonfuel (feedstock), the energy use for the production of net imported coke, lime, pellets, pig iron, DRI, oxygen, and ingots, blooms, billets, and slabs is also included in the calculation of energy intensity for this study in order to have a more accurate and fair comparison of the energy intensity of the industry in both countries. This is done to eliminate the effect of differences in the share of imported coke, lime, DRI, and pig iron on the energy intensity of the industry in the two countries. For the base case scenario of this study, the WORLDSTEEL conversion factors for these auxiliary/intermediary products used in the iron and steel industry are used.

The total electricity and fuel consumption for the production of iron and steel in the U.S. based on the defined boundary of this study are presented in Table 6. The first row of the table is energy use in 2006 based on the EIA fuel conversion factors from U.S. DOE/EIA (2010e, f, g). For details of the calculation we refer you to Hasanbeigi et al. (2011).

Table 6: Total Electricity and Fuel Consumption for Iron and Steel Production in the U.S. Based on Study Boundaries

Item	Electricity Use (GWh)	Fuel Use (TJ)	Final (TJ)	Primary (TJ) *
Energy use reported for the iron and steel industry in EIA *(excluding the energy use for production of intermediary products given below)*	51,198	912,623	1,096,936	1,481,942
Energy used for the production of net imported** oxygen	4,750	0	17,101	52,824
Energy used for the production of net imported pig iron	2,603	107,784	117,157	136,735
Energy used for the production of net imported direct reduced iron	809	33,473	36,383	42,463
Energy used for the rolling and finishing of net imported ingots, blooms, billets, and slabs	4,396	43,257	59,083	92,141
Embodied energy of net imported ingots, blooms, billets, and slabs	7,509	109,109	136,141	192,608
Energy used for the production of net imported coke	351	10,237	11,502	14,145
Energy used for the production of net imported lime	334	6,816	8,019	10,532
Energy used for the production of net imported pellets	0	103,530	103,530	103,530
Total Energy Consumption based on EIA fuel conversion factor	**71,951**	**1,326,830**	**1,585,853**	**2,126,919**

* In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with T&D losses, electricity use at the end-use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) and transmission and distribution losses.
**: Net import is to the steel industry based on the defined boundary.

3.2.2. Energy Use Data for the Chinese Iron and Steel Industry

According to the boundaries presented in Figure 1, the energy consumption of steel production is calculated and included in this analysis. The upstream energy consumption of net imported coke, pig iron, DRI, steel ingots and steel billets is presented in Table 7. Total energy use is adjusted for net trade in auxiliary and intermediate products. The first row of the table is energy use in 2006 based on the NBS (2010a). For details of the calculation we refer you to Hasanbeigi et al. (2011).

Table 7: Total Energy Consumption of China's Steel Industry Production in 2006

Component	Electricity Use (GWh)	Fuel Use (TJ)	Final (TJ)	Primary (TJ)
Reported energy consumption	174,293	8,593,558	9,221,013	10,515,967
Energy used for the production of purchased coke	5,883	488,395	509,574	553,283
Energy used for the production of net exports of pig iron	-114	-13,412	-13,822	-14,669
Energy used for the production of net imports of coal-based DRI	42	4,934	5,085	5,397
Energy used for the production of net imports of steel ingots	17	1,589	1,650	1,776
Energy used for the production of net exports of steel billets/slabs	-2,082	-192,304	-199,799	-215,268
Total energy consumption of steel industry with embodied energy of net imported/exported auxiliary/intermediary products included	178,039	8,882,760	9,523,701	10,846,487

Note 1: The negative values indicate the energy use by export products was subtracted.

Note 2: The reason that there is no energy use data given separately for lime and pellets is that the energy use for the production of these products is included in the reported energy consumption of the steel industry in China (first row of this table) and there is no import or export of these two products.

4. Comparison of Energy Intensity of Iron and Steel Production in China and the U.S.

In this study, “energy intensity” is chosen as the index of comparison for the Chinese and U.S. iron and steel industries. It presents, within the prescribed boundary (as illustrated in Figure 1), the index of energy consumption per tonne of crude steel during production.

$$\text{Energy intensity} = \frac{\text{Energy Consumption of the iron and steel industry within the prescribed boundary}}{\text{Crude steel production within the prescribed boundary}}$$

The energy intensity of steel production is influenced by industry structure, technology, fuel choice, and materials-e.g., availability of scrap steel. The effects of these variables are isolated in this study's scenario analyses as well as explanatory variables section. Section 4.3 of the paper presents six scenarios to compare a range of effects within the steel industry of China and the U.S.

4.1. Energy Intensity of Iron and Steel Production in the U.S.

Final energy intensity (energy use per tonne of crude steel) for the U.S. iron and steel industry in 2006 is provided in Table 8. This value is calculated using the production data and the electricity and fuel consumption data. Crude steel production in the U.S. in 2006 was 98.2 Mt. In addition, there were 8.261 Mt of net imported ingots, blooms, billets, and slabs in 2006. Since the energy use for the production of net imported ingots, blooms, billets, and slabs are included in the calculation of energy intensities, the amount of net imported ingots, blooms, billets, and slabs should be added to the crude steel production in the U.S. for energy intensities calculation. Thus, total crude steel production used for the calculation of energy intensities in 2006 was 106.461 Mt. Under the base case scenario, the total electricity and fuel consumption in iron and steel industry in U.S. in 2006 based on the defined boundary of this study explained above are 71,948 million kWh and 1,326,830 TJ, respectively. If these energy uses are divided by the production of crude steel given above, the electricity and fuel intensity can be calculated separately. The sum of the electricity and fuel intensity is given as the total final energy intensity.

Table 8: Base Case - Energy Intensity of the U.S. Iron and Steel Industry in 2006

Scenario	Electricity Intensity (kWh/t crude steel)	Fuel Intensity (GJ/t crude steel)	Final Energy Intensity (GJ/t crude steel)	Primary Energy Intensity with T&DGJ/t crude steel)	Primary Energy Intensity without T&D (GJ/t crude steel)
Base case	675.84	12.46	14.90	19.98	19.47

[2] In primary energy without transmission and distribution losses (T&D), electricity use at the end-use is converted to the primary energy sources by taking into account *only* the power generation efficiency (average net heat rate of power plants). This is done because in Chinese statistics it is common to do the conversion for electricity from final to primary energy without taking into account the T&D losses. Thus, for consistency, we have reported both types of primary energy calculated with international standard (with T&D losses) and Chinese standard (without T&D losses).

Total final energy intensity of the US iron and steel industry using the U.S. country-specific energy conversion factors for the purchased coke and auxiliary/intermediary products instead of WORLDSTEEL conversion factor would be 14.5 GJ/tonne crude steel, which is around 2.7% less than the intensity calculated above (see Table 8) using WORLDSTEEL conversion factors.

4.2. Energy Intensity of Iron and Steel Production in China

Table 9 shows the energy intensity (energy consumption per tonne crude steel) calculated based on the 2006 revised energy data given in the China Energy Statistical Yearbook 2009 (NBS, 2010a). The same methodology applied to the U.S. for taking into account the embodied energy of auxiliary/intermediary products is also applied to China. As can be seen from Table 8 and Table 9, the electricity intensity of the steel production in U.S. is significantly higher compared to China. This is because of higher share of EAF steel production in the U.S. (56.9% in 2006) compared to that in China (10.5% in 2006). The fuel and final energy intensity in the U.S., however, is much lower compared to China mainly because of higher share of EAF steel production in the U.S. Other factors causing the differences between energy intensities are the level of penetration of energy-efficient technologies, the age of the equipments, the scale of production equipment, fuel shares in the iron and steel industry, and the final steel product mix in both countries. These variables are discussed in our main report (Hasanbeigi et al. 2011).

Table 9: 2006 Energy Consumption and Intensity of Iron and Steel Production in China

Scenario	Electricity Intensity (kWh/t crude steel)	Fuel Intensity (GJ/t crude steel)	Final Energy Intensity (GJ/t crude steel)	Primary Energy Intensity with T&DGJ/t crude steel)	Primary Energy Intensity without T&D (GJ/t crude steel)
Base case	431.66	21.54	23.11	26.30	25.97

4.3. Scenario Analyses

In addition to the base case presented above, six variations to the base case were calculated to examine the impact of different assumptions on the iron and steel production energy intensity value for each country. The purpose of this scenario analysis is to determine which variables are most important for explaining energy intensity differences between China and the U.S. The first scenario uses IEA typical fuel conversion factors (instead of country-specific fuel conversion factors used in the base case), country-specific electricity conversion factors, and WORLDSTEEL conversion factors for auxiliary/intermediary products. This scenario is intended to isolate the impact of the use of country-specific conversion factors on the overall comparative intensity.

The second scenario uses the country-specific fuel conversion factors, WORLDSTEEL electricity conversion factors for converting electricity from final to primary energy (9.8 MJ/kWh) (instead of country-specific electricity conversion factors used on the base case), and WORLDSTEEL conversion factors for auxiliary/intermediary products. This scenario is intended to analyze the impact on energy intensity caused by change of electric power conversion factor.

The third scenario uses the IEA typical fuel conversion factors (instead of country-specific fuel conversion factors used in the base case), WORLDSTEEL electricity conversion factors (9.8 MJ/kWh) ((instead of country-specific electricity conversion factors used on the base case), and the WORLDSTEEL conversion factors for auxiliary/intermediary products. The purpose of this scenario is to remove the effect of country-specific conversion factors and focus the intensity comparison on structural and efficiency effects.

The fourth scenario uses the country-specific fuel conversion factors, country-specific electricity conversion factors, WORLDSTEEL conversion factors for auxiliary/intermediary products, and China's EAF ratio in 2006 used for U.S. energy intensity calculation. This scenario is intended to analyze the impact on energy consumption caused by a change of the EAF ratio.

The fifth scenario uses the IEA typical fuel conversion factors, WORLDSTEEL electricity conversion factors (9.8MJ/kWh), WORLDSTEEL conversion factors for auxiliary/intermediary products, and China's EAF ratio in 2006 used for U.S. energy intensity calculation. This scenario is the same as the third scenario, but takes into account the impact on energy consumption caused by a change of EAF ratio.

Finally, the sixth scenario uses the country-specific fuel conversion factors, WORLDSTEEL conversion factors for auxiliary/intermediary products, and China's final to primary electricity conversion factor for U.S. energy intensity calculation. This scenario shows the impact of the different power generation efficiencies in each country on the primary energy intensity. Table 10 shows the results for all scenarios developed for China and the U.S. One of the most interesting scenarios that gives useful insight into the effect of industry structure on the energy intensity is scenario 4. Scenario 4 for the U.S. should be compared with the base case for China and scenario 4 for China should be compared with base case in the U.S. This comparison presents the results of the base case and the six scenarios, providing information on the calculated electricity intensity, fuel intensity, final energy intensity, and primary energy intensity for the U.S. and China.

4.4. Explanatory Variables

The purpose of the analysis presented in this study is to develop and test a methodology for quantifying and comparing the energy intensity of steel production in China and the U.S. with defined boundaries and conversion factors. This section provides a discussion of some possible reasons that the energy intensity values differ in the two countries. Two explanatory variables are discussed in this paper: 1) the share of EAF steel in total steel production, 1) the age of steel manufacturing facilities in each country.

Table 10: Energy Intensity for the Iron and Steel Industry in China and the U.S. (2006)

No.	Scenarios	Country	Final Energy Intensity		Primary Energy Intensity*	
			GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel
Base	Country-specific fuel conversion factors Country-specific electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	U.S.	14.90	508.69	19.98	681.68
		China	23.11	788.53	26.30	897.29
1	IEA typical fuel conversion factors Country-specific electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	U.S.	14.83	506.49	19.91	679.48
		China	22.65	769.87	25.75	878.49
2	Country-specific fuel conversion factors WORLDSTEEL electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	U.S.	14.90	508.69	19.09	651.24
		China	23.11	788.69	25.77	879.45
3	IEA typical fuel conversion factors WORLDSTEEL electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	U.S.	14.83	506.49	19.02	649.04
		China	22.65	769.87	25.23	860.88
4a	Country-specific fuel conversion factors Country-specific electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products China 2006 EAF ratio used for U.S.	U.S.	22.96	783.32	26.08	889.94
	(Base Scenario) Country-specific fuel conversion factors Country-specific electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	China	23.11	788.53	26.30	897.29
4b	(Base Scenario) Country-specific fuel conversion factors Country-specific electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	U.S.	14.90	508.69	19.98	681.68
	Country-specific fuel conversion factors Country-specific electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products U.S. 2006 EAF ratio used for China	China	18.44	629.19	22.54	769.24
5a	IEA typical fuel conversion factors WORLDSTEEL electricity conversion factors	U.S.	23.04	786.03	26.09	890.27

No.	Scenarios	Country	Final Energy Intensity		Primary Energy Intensity*	
			GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel
	WORLDSTEEL conversion factors aux/intermediary products China 2006 EAF ratio used for U.S.					
	(Scenario 3) IEA typical fuel conversion factors WORLDSTEEL electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	China	22.65	769.87	25.23	860.88
5b	(Scenario 3) IEA typical fuel conversion factors WORLDSTEEL electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products	U.S.	14.83	506.49	19.02	649.04
	IEA typical fuel conversion factors WORLDSTEEL electricity conversion factors WORLDSTEEL conversion factors aux/intermediary products U.S. 2006 EAF ratio used for China	China	17.90	610.76	21.38	729.50
6	Country-specific fuel conversion factors WORLDSTEEL conversion factors aux/intermediary products China final to primary electricity conversion factor for U.S. energy intensity calculation	U.S.	14.90	508.69	19.92	679.60
	Country-specific fuel conversion factors WORLDSTEEL conversion factors aux/intermediary products U.S. final to primary electricity conversion factor for China energy intensity calculation	China	23.11	788.53	26.33	898.51

* For the base Scenario and Scenarios 1, 4 and 6 the primary energy value includes T&D losses, whereas for Scenarios 2, 3, and 5 the primary energy value is calculated based on the WORLDSTEEL conversion factor which excludes T&D losses. T&D losses will be added to this calculation if the values can be identified.

4.4.1. Structure of the Steel Manufacturing Sector

The structure of the steel manufacturing sector is one of the key variables that explains the difference in energy intensity values in China and the U.S. since EAF steel production uses significantly less energy for the production of one tonne of steel. In 2006, the share of EAF steel production in total steel production was 10.5% in China and 56.9% in the U.S. The world average EAF production in 2006 was 31.6%. Scenarios 4 and 5 calculate the total U.S. energy intensity using the share of EAFs in China and the total Chinese energy intensity using the share of EAFs in the U.S., respectively.

Scenario 4a, which relies on country-specific fuel and electricity conversion factors and WORLDSTEEL conversion factors for auxiliary and intermediate products, found that if the U.S. iron and steel industry had the same structure as the Chinese iron and steel industry in terms of the shares of EAF steel, the final energy intensity of U.S. steel production would be 22.96 GJ/tonne crude steel using the same conversion factors. This value should be compared to the Base Scenario for China which resulted in a final energy intensity of 23.11 GJ/tonne crude steel using the same conversion factors. Conversely, Scenario 4b shows that if the Chinese steel industry had the same structure as the U.S. steel industry in terms of shares of EAF steel, the final energy intensity of Chinese steel production would be 18.44

GJ/tonne crude steel using the same conversion factors. This value should be compared to the Base Scenario for the U.S which resulted in a final energy intensity of 14.9 GJ/tonne crude steel.

Scenario 5a, which uses IEA typical fuel conversion factors and WORLDSTEEL conversion factors for electricity and auxiliary and intermediate products, found that if the U.S. iron and steel industry had the same structure as the Chinese iron and steel industry in terms of the shares of EAF steel, the final energy intensity of U.S. steel production would be 23.04 GJ/tonne crude steel. This value should be compared to Scenario 3 for China, in which the resulting steel energy intensity was calculated to be 22.65 GJ/tonne crude steel using the same conversion factors. Conversely, Scenario 5b shows that if the Chinese steel industry had the same structure as the U.S. steel industry in terms of shares of EAF steel, the final energy intensity of Chinese steel production would be 17.9 GJ/tonne crude steel using the same conversion factors. This value should be compared to Scenario 3 for the U.S which resulted in a final energy intensity of 14.83 GJ/tonne crude steel using the same conversion factors.

4.4.2. Age of Steel Manufacturing Facilities

Most of China's steel production capacity has been constructed since 2000, when annual production jumped from 129 Mt to 630 Mt in 2010. During that same time, production in the U.S. dropped from 102 Mt to 90 Mt. While there are no data available on the exact age of each steel production line (e.g. BF, BOF, or EAF) in China, we can infer from the growth in production capacity between 2000 and 2010 that in 2011, about 500 Mt of production (or about 80%) is from production lines that are 10 years old or younger. In contrast, the average age of BOF vessels in the U.S. is 31.5 years (AIST, 2010a) and the average age of EAF furnaces in the U.S. is 30.9 years (AIST, 2010b). Even though the vessels have been relined and other upgrades have been made to the U.S. facilities, they are overall older than most of the steel production facilities in China. However, it should also be noted that not all of the new Chinese plants have necessarily installed the most energy-efficient technologies.

5. Findings

A key finding of this analysis is that it is possible to develop a methodology in which the energy intensity of steel production of different countries can be compared. The methodology must clearly define the boundaries and energy conversion factors used in the analysis. The boundary definition must address how to account for imported and exported inputs and intermediate products.

Another key finding is that it is not possible to accurately compare the energy intensity of steel production of different countries without considering multiple scenarios. There is no single scenario that best compares different countries; each scenario presents different issues in terms of the accuracy and "fairness" of the comparison. For example, for this comparison of the U.S. and Chinese steel industries, the results change when the difference in production structure is taken into account when comparing the energy intensity values. For other countries, key differences might be found in the fuel or electricity conversion factors. Thus, it is necessary to present multiple scenarios to accurately convey the reasons behind the calculated energy intensities.

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